Longterm Outcomes after Combat Casualty Emergency Department Thoracotomy

Jason W Edens, MD, Alec C Beekley, MD, FACS, Kevin K Chung, MD, E Darrin Cox, MD, FACS, Brian J Eastridge, MD, FACS, John B Holcomb, MD, FACS, Lorne H Blackbourne, MD, FACS

BACKGROUND: The incidence, survival, and blood product use after emergency department thoracotomy (EDT) in combat casualties is unknown.

STUDY DESIGN: We performed a prospective and retrospective observational study of EDT at a combat support hospital in Iraq, evaluating the impact of injury mechanisms, blood product use, mortality, and longterm neurologic outcomes of survivors.

RESULTS: From November 2003 to December 2007, 12,536 trauma admissions resulted in 101 EDTs (0.01%). In patients undergoing EDT, penetrating trauma from explosions and firearms accounted for the majority of injuries (93%). There were no survivors after EDT for blunt trauma (n = 7). The areas of primary penetrating injury were the abdomen (30%), thorax (40%), and extremities (22%). Twelve percent (12 of 101) of all patients survived until evacuation, with the overall survival rate (8 to 26 months) of US casualties at 11% (6 of 53). There was no difference in survival seen in either injury mechanism or primary injury location. Signs of life were present in all overall survivors. Cardiopulmonary resuscitation (CPR) was performed in 92% (93 of 101) of all patients, and in 75% (9 of 12) of those evacuated. Mean (±SD) transfusion requirements for all patients were 15.0 ± 12.7 U of RBC and 7.3 ± 8.7 U of fresh frozen plasma during the initial resuscitation. Survivors demonstrated higher fresh frozen plasma:RBC ratios. All survivors were neurologically intact.

CONCLUSIONS: In the combat casualty with penetrating injury, arriving with signs of life, receiving CPR, and undergoing EDT, longterm survival with normal neurologic outcomes is possible. CPR is not a contraindication to performance of EDT in penetrating injuries if signs of life are present. A large amount of blood products are used in the resuscitation of EDT patients. (J Am Coll Surg 2009;209:188–197. © 2009 by the American College of Surgeons)

In the resuscitation of severely injured trauma patients, emergency department thoracotomy (EDT) is performed as a salvage maneuver for select patients who arrive in extremis or who arrest shortly after arrival. The goals of EDT are to release pericardial tamponade or tension pneumothorax, to directly control and repair intrathoracic hemorrhage, to allow open cardiac massage, and to cross clamp the thoracic aorta, restoring and maintaining perfusion to the heart and brain and preventing additional blood loss from distal sites of hemorrhage.[1] The appropriate indications for EDT have been debated since its inception, mainly because of the low survival rates associated with the procedure, particularly in patients who suffer blunt trauma. Although literature abounds on the subject of EDT in civilian trauma, the role of EDT in combat casualties remains undefined. Variables unique to military trauma contribute to the need to optimize the selective use of EDT in the combat setting. These variables include wounding patterns substantially different from those in civilian trauma patients, frequent multiple simultaneous casualties, resource limitations, transportation and evacuation challenges, and austere practice environments.

In response to the unique nature of military medicine, the Department of Defense has published the *Emergency War Surgery* handbook, which provides treatment guidelines for those deployed in the combat setting. Its recom-

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From the United States Army Institute of Surgical Research, Fort Sam Houston, TX (Edens, Chung, Eastridge, Holcomb, Blackbourne); the Department of General Surgery, Madigan Army Medical Center, Fort Lewis, WA (Beekley); and the 745th Forward Surgical Team, Fort Bliss, TX (Cox).

Correspondence address: Lorne H Blackbourne, MD, US Army Institute of Surgical Research, 3400 Rawley E Chambers Ave, Fort Sam Houston, TX 78234.

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Abbreviations and Acronyms

CSH = combat support hospital
ED = emergency department
EDT = emergency department thoracotomy
FFP = fresh frozen plasma
GCS = Glasgow Coma Scale
ISS = Injury Severity Score

mendations for performance of EDT state that it is "only indicated in penetrating chest injury [in patients] *in extremis* or with recent loss of vital signs."[2] Although no reviews have been published from the US military experience, DiGiacomo and Odom[3] attempted to extrapolate their experiences at a Level I trauma center to define the role of EDT as it applies to military medicine. Their recommendations reflect those set forth in *Emergency War Surgery*, stating that only patients presenting with penetrating thoracic injury who have vital signs on arrival or a witnessed cardiac arrest should be triaged to top priority for EDT. Despite these guidelines, EDT continues to be used as a resuscitative adjunct in severely injured combat casualties with a variety of injuries, not just exclusively in penetrating thoracic trauma.

Because of the lack of published information on EDT in the combat environment, we sought to evaluate and analyze instances of its performance in the current war, with the intention to validate and improve treatment guidelines and explore the indications for the use of EDT in critically injured combat casualties. Additionally, we sought to determine the outcomes of any survivors, including neurologic function, and the use of blood and blood products.

METHODS

An Institutional Review Board-approved prospective and retrospective observational study of all patients undergoing an EDT at a combat support hospital (CSH) in Iraq from November 2003 to December 2007 was performed. EDT was defined as a resuscitative thoracotomy performed as a primary intervention before the patient left the emergency department. Resuscitative thoracotomies performed after the patient left the emergency department and had another primary operative intervention initiated (eg, resuscitative thoracotomy performed in the operating room or ICU after laparotomy had been done) were excluded. The CSH is the highest level of medical care available within the combat zone and provides the majority of initial surgical care to severely wounded soldiers in the theater of operations. Aside from an absence of MRI, interventional radiology, and cardiopulmonary bypass, the CSH has all the capabilities of a modern Level I trauma center.

Pertinent demographic data including age, gender, nationality, mechanism and type of injury, and area of injury were collected retrospectively for patients treated from November 2003 to May 2007, then prospectively by a deployed combat casualty research team from May 2007 to December 2007. Time of injury and arrival (if available), performance of CPR in the prehospital or emergency department setting, admission laboratory and physiologic data, medical and surgical interventions, and transfusion requirements were retrospectively obtained by chart review. Outcomes data and injury severity scores were obtained using the United States Army Joint Theater Trauma Registry (JTTR) and the Joint Patient Tracking Application (JPTA). Signs of life were defined as the presence of any one of the following parameters: cardiac electrical activity on electrocardiogram, agonal respirations, palpable pulse (femoral, radial, or carotid), measurable blood pressure, pupillary response, and extremity movement.

All patient injuries were catalogued, and patients were grouped based on primary locations of injury that led to either death or the need for EDT. Injuries were characterized and compared based on mechanism and body area injured and included injuries to multiple body systems. Blood transfusion data were analyzed and grouped into total transfusion requirements in the initial 24 hour resuscitation period, transfusion requirements in the emergency department, and transfusion requirements from injury through the operating room. Patients who died in the emergency department were excluded from the transfusion totals of patients surviving through the operating room. In instances of fresh whole blood use, we used the method of Borgman and colleagues[4] for inclusion of fresh whole blood into both the RBC and fresh frozen plasma (FFP) transfusion totals.

All US military, US civilian, and nondetainee host national patients who underwent EDT at the CSH were included in this study. Because host nation patients are transferred from the CSH to local Iraqi health care systems and because many times no means of identifying these patients is possible, followup beyond the time of evacuation is unobtainable. For this reason, the study subjects are divided into two groups. The first group included all patients who underwent EDT at the CSH and were followed until evacuation from the CSH or until death. The second group included all US military and US civilian patients undergoing EDT at the CSH and followed until discharge from a medical treatment facility within the US or until death; this group of patients had followup throughout their entire hospital course, with neurologic outcomes documented in the overall surviving patients.

Table 1. Demographics and Clinical Characteristics of Emergency Department Thoracotomy Patients

Demographics and clinical characteristics	Data
Age, y	25.6 ± 8.9
Male	96 (95)
Nationality	
US military	50 (49.5)
US civilian	3 (3)
Foreign national	48 (47.5)
Injury type	
Penetrating	94 (93)
Blunt	7 (7)
Injury mechanism	
Explosion	56 (55)
Firearms	42 (42)
Motor vehicle crash	1 (1)
Helicopter crash	1 (1)
Building collapse	1 (1)
Primary injury location	
Thorax	40 (40)
Abdomen	30 (30)
Extremity	22 (22)
Blunt	7 (7)
Head/neck	2 (2)
Signs of life	82 (81)
Field CPR	35 (35)
ED CPR	93 (92)
Initial GCS	5.5 ± 4.2
Initial cardiac rhythm (EKG)	
Sinus tachycardia	37 (39)
Bradycardia	33 (34)
Asystole	18 (19)
Ventricular tachycardia	3 (3)
Normal sinus rhythm	3 (3)
Fibrillation	2 (2)
Laboratory values	
pH	6.99 ± 0.22
Base deficit, mmol/L	16.2 ± 8.7
Hematocrit, %	29.03 ± 10.03
Platelets × 10^3/mcl	155 ± 104
INR	3.1 ± 2.7
Injury Severity Score	35.5 ± 22.0
Restore rhythm (post-EDT)	49 (49)
Survival to OR	46 (46)
Survival to CSH evacuation	12 (12)

Unless stated otherwise, values are mean ± SD or n (%).
CSH, combat support hospital; ED, emergency department; EDT, emergency department thoracotomy; EKG, electrocardiogram; GCS, Glasgow Coma Score; INR, international normalized ratio; OR, operating room.

Statistical analysis was performed with SAS version 9.1. Categorical data were analyzed using chi-square tests. All continuous data were analyzed using Wilcoxon tests for nonparametric distributions and Student's *t*-test for parametric distributions when appropriate. Statistical significance was set at $p < 0.05$. Values in the text are reported as mean ± standard deviation (SD) unless otherwise indicated.

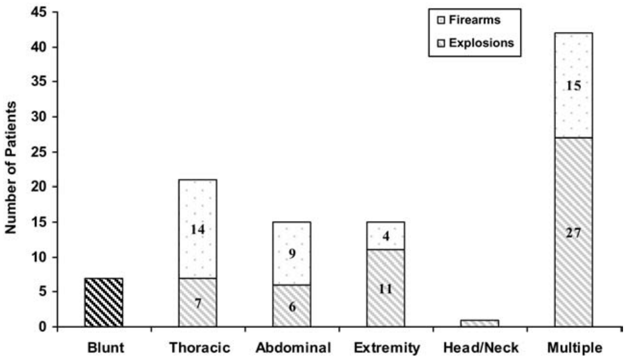

Figure 1. Overall injury patterns in patients arriving at the combat support hospital. There were seven patients with blunt injury. Of the isolated thoracic injuries, 14 occurred from firearms and 7 occurred from explosions. Isolated abdominal injuries from firearms and explosions occurred in 9 and 6 patients, isolated extremity injuries in 4 and 11 patients and multiple injuries in 15 and 27 patients, respectively. There was one patient with an isolated head and neck injury from an explosion. White bar, firearms; gray bar, explosions.

RESULTS

From November 2003 through December 2007, the CSH had 12,536 trauma admissions. A total of 101 EDTs were performed during this time period, representing 0.01% of total trauma admissions. Table 1 summarizes demographics and clinical characteristics of all patients who underwent EDT. There were 53 US military or civilian patients and 48 host national patients. Of these patients, 95% were men with an average age of 26 ± 9 years. The great majority of EDTs were performed for penetrating injuries (93%) resulting from explosions (55%) and firearms (42%). The primary locations of penetrating injury in EDT patients were the thorax (40%), the abdomen (30%), the extremities (22%), and the head and neck (2%). Many patients (42%) suffered injuries in multiple areas (Fig. 1).

Patients were brought to the CSH with 39 (39%) having loss of vital signs in the field and 35 (35%) undergoing cardiopulmonary resuscitation before arrival. Signs of life were seen in the majority of patients (81%) on arrival at the CSH. After admission, 93 patients (92%) underwent CPR before EDT was performed. Initial emergency department electrocardiograms exhibited a variety of electrical patterns including sinus tachycardia, 37%; bradycardia, 34%; asystole, 19%; ventricular tachycardia, 3%; normal sinus rhythm, 3%; and fibrillation, 2%. Initial mean Glasgow Coma Scale (GCS) of all patients was 5.5 ± 4.2. The mean Injury Severity Score (ISS) was 35.5 ± 22.0. The average

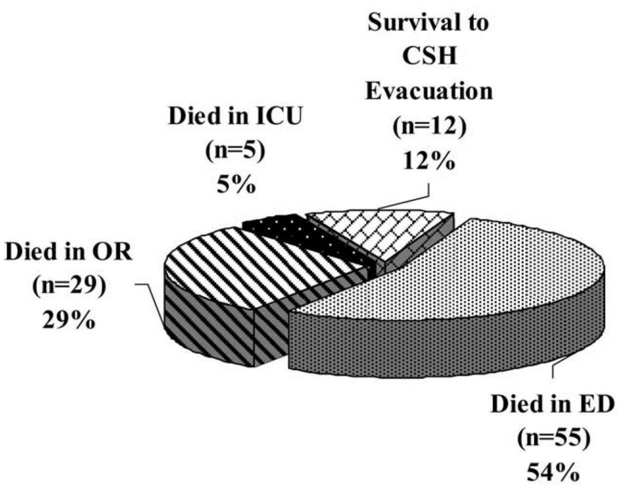

Figure 2. Outcomes after performance of emergency department thoracotomy (EDT). A total of 101 patients underwent EDT at the combat support hospital (CSH). Fifty-five patients died after EDT in the emergency department (ED). Of the 46 patients who survived the ED, 29 died in the operating room (OR). Five patients died while in the ICU. Twelve patients survived until evacuation from the CSH.

patient was acidotic, anemic, and coagulopathic from the injuries.

Twelve of 101 patients (12%) survived until evacuation to a higher level of care or transfer to the local national health system. Fifty-five patients (54%) died in the emergency department (ED), 29 patients (29%) died in the operating room, and 5 patients (5%) died in the ICU (Fig. 2). EDT restored a cardiac rhythm in 49 patients (49%).

There were no differences in the survival percentages among injury mechanism, primary injury location, or overall injury pattern in patients undergoing EDT (Table 2). Injuries from explosions resulted in a 12.5% survival from the CSH; injuries from firearms resulted in a 12% survival. There were survivors among all penetrating primary injury locations seen at the CSH. When looking at overall injury patterns, survivors at the CSH included those with isolated thoracic injuries, isolated extremity injuries, and multiple injuries. There were no patients surviving to evacuation after EDT for blunt injury (n = 7).

Table 3 compares survivors and nonsurvivors from the CSH. There was no difference in presence of signs of life, performance of prehospital CPR, or mean ISS between groups. Survival until evacuation did occur in patients receiving CPR both prehospital (5 of 35, 14%) and in the ED (9 of 93, 10%). Nonsurvivors were significantly more likely to undergo ED CPR than survivors. There was one survivor from the CSH who was without signs of life on admission, but longterm followup was available for this patient, who subsequently died after evacuation to a higher level of care. The initial GCS was significantly higher in survivors. Injury mechanisms and primary injury locations were not different between survivors and nonsurvivors.

There was no difference in the mean ISS, the performance of prehospital or ED CPR, or initial GCS between

Table 2. Breakdown of Survivors by Injury Mechanism, Primary Location of Injury, and Injury Pattern

	Combat support hospital		US military or civilian	
Injury characteristic	**Survival, %**	**Survivors, n**	**Survival, %**	**Survivors, n**
Injury mechanism				
Explosion	12.5	7/56	12	5/43
Firearms	12	5/42	12.5	1/8
Primary location				
Blunt	0	0/7	0	0/6
Thorax	15	6/40	9	2/23
Abdomen	7	2/30	17	2/12
Extremity	14	3/22	10	1/10
Head/neck	50	1/2	50	1/2
Injury pattern				
Blunt	0	0/7	0	0/6
Thorax	9.5	2/21	10	1/10
Abdomen	0	0/15	0	0/5
Extremity	7	1/15	14	1/7
Head/neck	0	0/1	0	0/1
Multiple	21	9/42	17	4/24

There were no differences in survival percentage among injury mechanism, primary locations, or overall injury pattern in either group. There were no survivors from blunt injuries. Survivors were seen in all primary locations of penetrating injuries. When comparing survivors by overall injury pattern, there were survivors of isolated thoracic injuries, isolated extremity injuries, and patients with injuries to multiple locations.

Table 3. Comparison of Survivors and Nonsurvivors at the Combat Support Hospital and Between US Military and US Civilian Patients

	CSH		US military and civilians	
Variable	**Survivors (n = 12)**	**Nonsurvivors (n = 89)**	**Survivors (n = 6)**	**Nonsurvivors (n = 47)**
ED signs of life	11 (92)	71 (80)	6 (100)	34 (72)
Initial GCS*	8.3 ± 5.7	5.1 ± 3.8	10.7 ± 6.0	4.5 ± 3.4
Prehospital CPR	5 (42)	30 (34)	2 (33)	24 (51)
ED CPR†	9 (75)	84 (94)	4 (67)	47 (100)
ISS	42.6 ± 20.8	34.2 ± 22.2	35.2 ± 9.1	38.6 ± 22.3
Injury mechanism				
Explosion	7 (58)	49 (55)	5 (83)	38 (81)
Firearms	5 (42)	37 (42)	1 (17)	7 (15)
Primary location				
Blunt	0 (0)	7 (8)	0 (0)	6 (13)
Thorax	6 (50)	34 (38)	2 (33)	21 (45)
Abdomen	2 (17)	28 (31)	2 (33)	10 (21)
Extremity	3 (25)	19 (21)	1 (17)	9 (19)
Head/neck	1 (8)	1 (1)	1 (17)	1 (2)

Data are expressed as n (%) or mean ± SD.
There was no difference in ED signs of life, prehospital CPR, or mean ISS between survivors and nonsurvivors in either group. The initial GCS was significantly higher in survivors than in nonsurvivors in both groups ($p < 0.05$). Additionally, the performance of ED CPR was significantly higher in nonsurvivors than in survivors ($p < 0.05$). There was no difference in injury mechanisms or primary injury locations between survivors and nonsurvivors.
*Wilcoxon two-sample test.
†Chi-square test.
CSH, combat support hospital; ED, emergency department; GCS, Glasgow Coma Score; ISS, Injury Severity Score.

overall injury patterns (Table 4). Patients with isolated thoracic injuries were significantly more likely to be victims of firearms than patients with isolated extremity injuries or multiple injuries at the CSH. Patients with isolated thoracic injuries were also significantly less likely than patients with isolated extremity injuries and multiple injuries to exhibit signs of life on admission to the CSH.

Ninety-two patients received transfusion of blood or blood products during the 24-hour initial resuscitation period surrounding EDT. Fresh whole blood was used in 13 patients (14%). Patients were transfused a total of 1,380 U of RBC and 673 U of FFP, giving means of 15.0 ± 12.7 U and 7.3 ± 8.7 U, respectively, during their initial 24-hour resuscitation period (Fig. 3). Patients surviving through evacuation received a mean of 5.7 ± 2.1 U of RBC and 2.8 ± 1.0 U of FFP during their course in the ED, and 20.9 ± 16.1 U of RBC and 14.1 ± 9.0 U of FFP through their operating room course; as compared with nonsurvivors, 6.0 ± 5.2 U of RBC and 2.3 ± 3.0 U of FFP in the ED, and 20.7 ± 9.3 U of RBC and 9.6 ± 8.0 U of FFP in the operating room. When the amounts of FFP transfused relative to the amounts of RBC transfused were compared, we found that patients surviving through evacuation had FFP:RBC ratios of 1:2 and 1:1.3 (emergency department and operating room) as compared with 1:3.7 and 1:2.4 for nonsurvivors ($p = 0.002$ and $p = 0.001$, Wilcoxon).

When US military and civilian data were analyzed, similar results were seen. No differences were seen in survival percentages of injury mechanism, primary injury location, or overall pattern of injury (Table 2). Survivors were seen in all areas of penetrating primary injury location, and in isolated thoracic, isolated extremity, and in patients with multiple injuries. Survivors underwent both prehospital (2 of 6, 33% survivors) and ED CPR (4 of 6, 67% survivors), although all survivors had signs of life on arrival at the CSH (Table 3). The initial GCS was significantly higher in survivors, and nonsurvivors were significantly more likely to undergo ED CPR than survivors. Patients who suffered multiple injuries and isolated extremity injuries were significantly more likely to be the victims of explosions than those with isolated thoracic injuries (Table 4). There were no differences in the presence of signs of life on admission, performance of prehospital or ED CPR, initial GCS, or mean ISS between overall injury patterns in US military and civilian patients. US military and civilian patients were transfused a total of 833 U of RBC and 417 U of FFP, with means of 16.7 ± 14.4 U of RBC and 8.3 ± 9.5 U of FFP. Surviving patients received a mean of 5.3 ± 2.1 U of RBC and 2.7 ± 1.0 U of FFP during their ED course as compared with 5.2 ± 4.4 U of RBC and 1.9 ± 2.2 U of FFP. The FFP:RBC ratio was significantly higher in surviving patients (1:2 versus 1:3.8, $p = 0.01$; Wilcoxon). Comparison of transfusion totals through the operating room be-

Table 4. Comparison of Overall Injury Patterns at the Combat Support Hospital and Between US Military and US Civilian Patients

	Injury patterns									
	CSH					US military and civilian				
Variable	**Blunt (n = 7)**	**Thorax (n = 21)**	**Abdomen (n = 15)**	**Extremity (n = 15)**	**Multiple (n = 42)**	**Blunt (n = 6)**	**Thorax (n = 10)**	**Abdomen (n = 5)**	**Extremity (n = 7)**	**Multiple (n = 24)**
Explosion		7 (33)*	6 (40)	11 (73)*	27 (64)*		5 (50)*	4 (80)	7 (100)*	22 (92)*
Firearms		14 (67)*	9 (60)	4 (27)*	15 (36)*		5 (50)*	1 (20)	0 (0)*	2 (8)*
ISS	40.4 ± 26.8	33.5 ± 26.1	19.5 ± 9.0	34.7 ± 11.2	39.4 ± 21.9	34.7 ± 24.2	36.0 ± 27.0	20.5 ± 3.7	36.5 ± 13.7	41.9 ± 19.5
SOL	6 (86)	12 (57)*	12 (80)	14 (93)*	37 (88)*	5 (83)	5 (50)	3 (60)	6 (86)	20 (83)
Prehospital CPR	5 (71)	9 (43)	6 (40)	5 (33)	10 (24)	5 (83)	5 (50)	2 (40)	5 (71)	9 (38)
ED CPR	7 (100)	18 (86)	15 (100)	15 (100)	37 (88)	6 (100)	9 (90	5 (100)	7 (100)	23 (96)
Initial GCS	3.4 ± 1.1	5.7 ± 4.2	4.6 ± 3.5	5.8 ± 4.5	6.1 ± 4.6	3.5 ± 1.2	5.0 ± 4.7	6.4 ± 5.0	5.1 ± 3.9	5.5 ± 4.6
Survival	0 (0)	2 (9.5)	0 (0)	1 (7)	9 (21)	0 (0)	1 (10)	0 (0)	1 (14)	4 (17)

Data are expressed as n (%) or mean ± SD.
Patients with isolated thoracic injuries were significantly more likely to be victims of firearms than patients with isolated extremity injuries or patients with multiple injuries in both groups ($p < 0.05$). SOL were significantly more likely to be present in patients with isolated extremity and multiple injuries than in isolated thoracic injuries at the CSH ($p < 0.05$); this was not seen between US military and civilian patients. There were no differences in mean ISS, prehospital CPR, ED CPR, or initial GCS between patients with different injury locations. There was no difference in survival according to overall injury location.
*Chi-square test.
CSH, combat support hospital; ED, emergency department; GCS, Glasgow Coma Score; ISS, Injury Severity Score; SOL, signs of life.

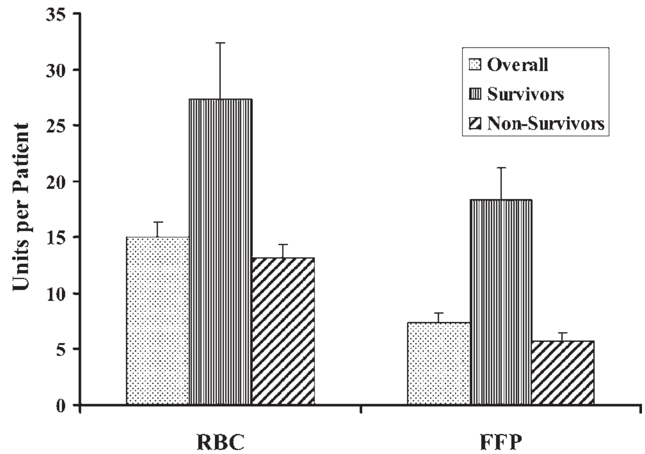

Figure 3. Blood product usage in the initial resuscitation of emergency department thoracotomy patients. Average total blood products transfused to all patients undergoing emergency department thoracotomy (EDT) were 15.0 ± 1.3* U of RBC and 7.3 ± 0.9* U of fresh frozen plasma (FFP). Survivors of the combat support hospital (CSH) received an average of 27.3 ± 5.1* U of RBC and 18.3 ± 2.9* U of FFP; nonsurvivors of the CSH received an average of 13.2 ± 1.2* U of RBC and 5.7 ± 0.8* U of FFP. *mean ± SEM. Light gray bar, overall; dark gray bar, survivors; diagonally striped bar, nonsurvivors.

tween survivors and nonsurvivors showed a total of 23.3 ± 21.7 U of RBC and 15.2 ± 11.5 U of FFP in survivors and a total of 21.4 ± 8.2 U of RBC and 10.2 ± 7.3 U of FFP in nonsurvivors. The FFP:RBC ratio was 1:1.3 in survivors as compared with 1:2.3 in nonsurvivors, although this was not significant ($p = 0.06$, Wilcoxon).

Seventeen percent (9 of 53) of US military and civilian patients survived through evacuation from the CSH, with 6 patients (11%) surviving their entire hospital course. Two patients died at a military treatment facility in Germany, each 3 days after injury. One patient died in a military hospital in the US 20 days after injury as the result of sepsis. All surviving patients had signs of life on arrival at the CSH (Table 5). Eighty-three percent of survivors (five of six) were involved in explosions, and 67% of patients suffered multiple injuries. All survivors were severely injured, with ISS > 20, and received large amounts of blood and blood products. Length of stay in the ICU varied among the survivors (range 5 to 70 days). The followup period for all survivors ranged from 8 to 26 months. All patients were neurologically intact on discharge from the hospital.

DISCUSSION

This is the largest study of EDT performed in a combat environment. The purpose of the study was to evaluate and analyze the use of EDT in combat situations, focusing on

Table 5. Characteristics of US Military/Civilian Survivors after Emergency Department Thoracotomy

Survivor	Injury mechanism	Primary injury location	Injuries	SOL	PH CPR	ED CPR	Initial cardiac rhythm	ISS	RBC, U	FFP, U	ICU LOS, d
1	Explosion	Extremity	Bilateral AKAs	Yes	Yes	Yes	Bradycardia	24	11	11	9
2	Explosion	Abdomen	Evisceration, splenic laceration, iliac artery/vein, pelvic fracture, left AKA	Yes	No	Yes	Sinus tachycardia	45	68	37	70
3	Explosion	Abdomen	Evisceration, spinal transaction, bilateral AKA, SAH/SDH	Yes	Yes	Yes	Bradycardia	38	46	32	40
4	Explosion	Head/Neck	Facial fractures, facial artery laceration, extremity shrapnel wounds	Yes	No	Yes	Sinus tachycardia	33	8	5	11
5	Explosion	Thorax	Left subclavian artery, left arm amputation, right femoral artery	Yes	No	No	Sinus tachycardia	45	24	27	6
6	Firearms	Thorax	Right atrium, right lung	Yes	No	No	Sinus tachycardia	26	36	16	5

There were survivors from both explosions and firearms, and from all primary injury locations. All survivors demonstrated SOL before performance of EDT. Prehospital CPR was performed in two patients; ED CPR was performed in four of the survivors. All patients were severely injured and required a large amount of RBCs and FFP. The length of stay in the ICU was highly variable among the survivors.

AKA, above knee amputation; ED, emergency department; EDT, emergency department thoracotomy; FFP, fresh frozen plasma; ISS, Injury Severity Score; LOS, length of stay; PH, prehospital; SAH, subarachnoid hemorrhage; SDH, subdural hematoma; SOL, signs of life.

outcomes of survivors including neurologic function. We also sought to obtain the indications for performance of EDT, specific injury patterns leading to EDT, and transfusion requirements associated with EDT in the combat environment. Our results indicate that in the combat casualty who has suffered a penetrating injury, regardless of primary location or overall injury pattern, arriving at the hospital with signs of life after receiving either prehospital or ED CPR, and undergoing EDT, longterm survival with normal neurologic outcomes is possible. For this reason, the military trauma surgeon must be proficient in the performance of EDT and must be prepared to use this procedure in situations in which it is warranted. Eleven percent (6 of 53) of US combat casualties survived hospitalization and remained neurologically intact after EDT in this study.

The use of EDT in critically injured trauma patients has been debated since its inception in the 1960s, after the use of EDT by Beall and colleagues[5,6] in moribund patients with penetrating chest trauma. Since that time, many authors and researchers have attempted to address the indications for EDT and to evaluate the mortality and neurologic outcomes of survivors associated with this procedure. In a large retrospective metaanalysis of 25 years of published data, Rhee and associates[7] presented 24 studies that included a total of 4,620 cases of EDT. These data showed an overall survival rate of 7.4%, with normal neurologic outcomes in 92.4% of surviving patients. Survival rates were best for patients with penetrating injuries (8.8%), specifically, cardiac injuries (19.7%) and stab wounds (16.8%). The American College of Surgeons Committee on Trauma reviewed 42 case series that included 7,035 EDTs for their Practice Management Guideline for EDT. Penetrating injuries showed a survival rate of 11.16% as compared with 1.6% in blunt trauma. Their Level II recommendations explained that EDT is best applied in patients with penetrating cardiac injuries, should be applied in patients with penetrating noncardiac thoracic injuries and exsanguinating abdominal vascular injuries, and should rarely be performed in patients with blunt injury.[8] The only published data on EDT in a combat environment showed a 23% (n = 4) survival rate in 17 patients undergoing EDT in the Lebanese War.[9] But the use of EDT was limited to only patients who presented "lifeless" or without cardiac activity after penetrating thoracic trauma. An additional article from the Lebanese War did not address the use of EDT in penetrating abdominal trauma.[10]

Mechanism and location of injury have been reported as factors influencing survival rates for EDT. Low survival rates have been universally reported for blunt trauma, and our study supports this finding because we had no survivors after blunt injury. Patients with penetrating injury have generally had higher survival rates, and all the survivors in this study suffered penetrating injuries. With regard to specific locations of injury, penetrating thoracic injuries have shown higher survival rates than other locations,[11-14] with thoracic stab wounds exhibiting the highest survival rates.[14,15-17] Although thoracic stab wounds are reported to result in the highest rates of survival, these types of injuries are not seen in this study because all penetrating trauma was related to firearms or explosions. In our study, survivors had not only thoracic injuries but also injuries to all locations of the body, including injuries to multiple areas. When looking at primary injury location in the US military and civilian group, thoracic injuries had a 9% survival rate, as compared with 17% for abdominal and 10% for extremity injuries (there was also a 50% survival rate for the head and neck group, although there were only two patients), but these differences in survival percentage were not significant. These data suggest that in our study, the location of the penetrating injury may not have been as important as the reversibility of the injury, that is, how quickly control of hemorrhage could be established to allow resuscitation of the patient. The injuries in the majority of survivors in this study (Table 5) demonstrated relatively reversible sources of hemorrhage from both early intervention (tourniquets for traumatic amputations) and from resuscitation with EDT (clamping of intrathoracic hemorrhage). Although EDT performed for penetrating thoracic trauma may allow for direct treatment of injuries, our data suggest that EDT performed as a resuscitative measure for penetrating injury to any location may lead to survival in these patients.

Penetrating abdominal injuries have caused great debate about the effectiveness of prelaparotomy EDT. When blood fills the abdomen and causes distention, the abdominal wall may provide a tamponade effect in which immediate release by laparotomy may cause additional hemodynamic instability and circulatory collapse. The goal in prelaparotomy EDT is to cross-clamp the aorta and control bleeding, allowing for more resuscitation and time to locate and repair intraabdominal injuries. Ledgerwood and coworkers[18] showed that prelaparotomy thoracotomy (performed in the operating room) led to a survival rate of 24% (7 of 29) and concluded that thoracic aortic occlusion before laparotomy can be beneficial in abdominal exsanguination. Branney and colleagues[15] showed that gunshot wounds to the abdomen were among the mechanisms of injury associated with the highest survival; 13% (7 of 56) of the patients in the study survived. More recently, Seamon and associates[19] reported a 16% survival rate (8 of 50) in patients undergoing prelaparotomy EDT. Our results support these studies, showing a survival rate of 17% (2 of 12 in the US military and civilian group) in patients with penetrating abdominal trauma as the primary location of injury.

Penetrating extremity injuries with exsanguination are a common source of current military trauma.[20-22] The adoption of liberal tourniquet use in the prehospital setting to control exsanguination has improved survival from these injuries.[23-25] Although hemorrhage may be controlled, the amount of blood lost before application of the tourniquet(s) may have been extensive. Such patients may already have sustained circulatory collapse, prompting the performance of EDT. Although rare in civilian studies, this potential role for EDT after extremity exsanguination has been addressed. Asensio and coworkers,[26] in studying femoral vessel injuries, showed that 5% (11 of 204) of all patients underwent EDT, with a survival rate of 27% (3 of 11). In a retrospective review of mortality associated with isolated penetrating extremity injury by Dorlac and colleagues,[27] they identified 14 patients who arrived at the hospital undergoing CPR or without vital signs. Of these, nine patients underwent EDT and none survived. Ivatury and associates[13] demonstrated a 25% (1 in 4) survival rate when EDT was performed for penetrating extremity trauma. Our study documented a survival rate of 10% (1 of 10 in the US military and civilian group) in patients undergoing EDT for extremity exsanguinations, providing a possible use for EDT in combat casualties with penetrating extremity trauma.

Although much of the literature has focused on single areas of injury and their relationship to the performance of EDT, the current conflict shows an abundance of multiple injuries and polytrauma from explosive devices not seen in civilian trauma.[20,21] Few studies have included patients with polytrauma. Velmahos and coauthors[14] found a 0.1% (n = 1) survival rate in 501 patients with multiple injuries. Ivatury and colleagues[13] showed a 4.8% (n = 2) survival rate in 42 patients with multiple injuries. This unique wounding pattern in military trauma with multiple injuries and multiple sources for exsanguination is relatively unstudied in its relation to EDT. EDT followed by aortic occlusion may allow for cessation of uncontrollable hemorrhage and time for surgical hemostasis to be obtained. Many patients in this study had multiple areas of injury (42%), and the highest survival rate was seen in this population of patients (17%, 4 of 24 in the US group), when categorizing patients into overall injury patterns.

The importance of rapid transport and field signs of life have been reported to affect the outcomes of EDT. Signs of life have been described to include cardiac electrical activity, respiratory effort, palpable pulse, pupillary response, spontaneous movement, and cranial nerve reflexes, although opinions among surgeons differ.[28] Absence of signs of life in the field has had uniformly poor survival rates.[12,13,29,30] Although performance of prehospital CPR has produced survivors,[31] the duration of CPR and time of transport have been shown to influence survival rates, and have led to many trauma centers adopting a rapid transport system ("scoop and run") for critically injured trauma patients, sometimes abandoning in-field stabilization measures.[32-34] These systems attempt to salvage as many patients as possible by allowing earlier care to critically injured patients. Although our study showed survival after performance of prehospital CPR (2 of 26 patients in the

US military and civilian group survived after prehospital CPR), all survivors had signs of life on arrival to the CSH. CPR was performed in the ED in 96% (51 of 53) of patients, with survival in 8% (4 of 51) in the US military and civilian group. There was limited documentation of transport times and the duration of CPR in our study to provide a complete timeline of events before the performance of EDT, so we were unable to ascertain the effects of transport on survival.

Not only is survival an important outcomes measure in the performance of EDT, but neurologic outcomes of those survivors are equally important. EDT acts as a resuscitative measure by occlusion of the thoracic aorta, improving coronary and cerebral perfusion. The occlusion of blood supply by cross-clamping of the aorta can cause spinal cord ischemia leading to paraplegia and paraparesis.[35] Additionally, because of hypovolemic shock from exsanguination with resultant ischemia of the brain, anoxic encephalopathy may occur in this population of patients. In the analysis of 303 survivors by Rhee and associates,[7] 92.4% (n = 280) of patients were neurologically intact on hospital discharge. All survivors in our study were neurologically intact after discharge from the hospital.

In patients undergoing EDT, massive transfusions are common because hemodynamic instability and circulatory collapse from exsanguination or thoracic injuries, including cardiac disruption, injury to the great vessels, and lung injury, have led to the need for EDT. In our study, all patients undergoing EDT used an average of 15.0 ± 12.7 U of RBC and 7.3 ± 8.7 U of FFP; survivors received an average of 20.9 ± 16.1 U of RBC and 14.1 ± 9.0 U of FFP during the initial 24-hour resuscitation period. Higher FFP:RBC transfusion ratios were observed in survivors, and were significant in survivors during the initial ED course, but not significant through the operating room course in the US military and civilian group. Higher FFP:RBC ratios early in the resuscitation period have been shown to be associated with decreased mortality in massively transfused patients.[4,36,37] Although the CSH has capabilities for massive blood and blood product administration, a plan for the use of this precious resource must be taken into account for patients who may need EDT in a mass casualty situation.

This study is subject to limitations. Because of the nature of the military environment, prehospital data cannot always be complete, and several important data points are missing from this study including time of transport to the CSH in both survivors and nonsurvivors, and duration of CPR before arrival at the CSH. The lack of followup for host national patients also hinders complete review for this study. After host national patients have been stabilized, they are transferred into the local health care system, in which followup is impossible. For this reason, we have presented the data in two major groups: all patients surviving until evacuation from the CSH and US military and civilian patients, for whom followup data for survivors can be obtained.

The results of this study are concordant with those from civilian studies. Our overall survival rate of 11% is comparable with the survival rates of two large retrospective reviews.[7,8] Both prehospital CPR and ED CPR were performed on survivors in this study, although all survivors exhibited signs of life on arrival at the CSH. There was no difference in survival percentage between explosion and firearm injuries, and there were no survivors after blunt trauma in this study. No specific primary location of injury had a significantly increased survival rate, and the patients in this study were more often the victims of multiple injuries. Large quantities of blood and blood products were used in the initial resuscitation of patients undergoing EDT, and this must be kept in mind by the military trauma surgeon who may be working with limited resources. This study is the largest study of EDT in a combat environment and will help to guide future deployed military surgeons in their decisions to perform EDT. We conclude that in the military casualty who has suffered a penetrating injury, who has arrived to the hospital with signs of life after receiving either prehospital or ED CPR, and who has undergone EDT, longterm survival with normal neurologic outcomes is possible. Although the results of this study support this conclusion, the trauma surgeon must ultimately make the decision to proceed with EDT after full evaluation of the clinical scenario.

Author Contributions

Study conception and design: Edens, Beekley, Blackbourne
Acquisition of data: Edens, Beekley, Cox, Blackbourne
Analysis and interpretation of data: Edens, Beekley, Chung, Cox, Eastridge, Holcomb, Blackbourne
Drafting of manuscript: Edens, Beekley, Chung
Critical revision: Edens, Beekley, Chung, Cox, Eastridge, Holcomb, Blackbourne

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